IEEE Std C57.121-1998
(Revision of IEEE Std C57.121-1988)

IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers

Sponsor

Transformers Committee
of the
IEEE Power Engineering Society

Approved 16 September 1998

IEEE-SA Standards Board

Abstract: The evaluation and handling procedures for less flammable hydrocarbon transformer insulating fluids are covered. The guide's purpose is to assist the transformer operator in receiving new fluids, filling transformers, and maintaining the fluids in serviceable condition.
Keywords: high molecular weight hydrocarbon fluid, HMWH fluid, hydrocarbon fluid, insulating fluid, less flammable hydrocarbon fluid, LFH fluid, transformer

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Print: ISBN 0-7381-1453-7 SH94693
PDF: ISBN 0-7381-1454-5 SS94693

Introduction

(This introduction is not a part of IEEE Std C57.121-1998, IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers.)

This guide was prepared by the Insulating Fluids Subcommittee of the Transformers Committee of the IEEE Power Engineering Society. The purpose of this guide is to identify standards for acceptance and maintenance of high-temperature hydrocarbon fluids in transformers.

At the time this guide was published, it was under consideration for approval as an American National Standard. The Accredited Standards Committee on Transformers, Regulators, and Reactors, C57, had the following members at the time this guide was sent to letter ballot:

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IEEE Guide for Acceptance and Maintenance of Less Flammable Hydrocarbon Fluid in Transformers

1. Overview

1.1 Scope

This guide recommends tests[1] and evaluation procedures, as well as criteria and methods of maintenance, for less flammable hydrocarbon (LFH) transformer insulating fluids. These liquids are also known as high molecular weight hydrocarbon (HMWH) fluids. HMWH dielectric fluids are hereby defined as those fluids having an ASTM D92 fire point of 300 °C or greater, being primarily composed of, but not restricted to, hydrocarbons. These fluids meet the requirements of the National Electrical Code® (NEC®) (NFPA 70-1999),[2] Article 450-23, as a less flammable dielectric for use in indoor applications when used in properly designed and installed transformers. Ester- and silicone-based fluids are not covered by this guide. Methods of reconditioning LFH fluids are also described. It is not the intent of this guide to address retrofilling transformers with LFH fluids. Any such substitution of fluids should be performed only after consultation with the manufacturers of fluid and equipment. Where instructions given by the transformer or fluid manufacturers differ from those given in this guide, the manufacturer's instructions are to be given preference.

1.2 Purpose

The purpose of this guide is to assist the transformer operator in evaluating and processing LFH fluids received in new transformers, as received from the fluid manufacturer for filling transformers, and as processed into such equipment. It also assists the operator in maintaining the fluid in serviceable condition. This guide, therefore, recommends standard tests and evaluation procedures, methods of reconditioning and reclaiming LFH fluids, and the analysis results at which these processes become necessary. It will also address the routines for restoring resistance to oxidation, where desired, by the addition of inhibitors.

[1]All test methods used to evaluate LFH fluids should be the latest versions available from the American Society of Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959, USA (http://www.astm.org/).
[2]Information on references can be found in Clause 2.

1.3 System design

The reliable performance of LFH fluids in an insulation system depends upon certain basic fluid characteristics that can affect overall apparatus characteristics. Such fluid characteristics are integral to equipment design for which the manufacturer has final responsibility. The reliable operation of the equipment in service, for which the transformer operator has final responsibility, also depends on maintaining certain basic fluid characteristics. Adherence to the recommended fluid characteristics will assist in obtaining the desired equipment characteristics. Other tests or verification of the integrity of the insulation system are often necessary.

The essential properties of insulating fluids used in transformers must be maintained if the fluid is to perform its multiple role as an electrical insulating and heat transfer agent. It must have adequate dielectric strength to withstand the electric stresses imposed in service. It must have a certain combination of thermal conductivity, specific heat, and viscosity so that its ability to transfer heat is sufficient for the particular equipment. It must have sufficiently high flash point and fire point to meet safety requirements. The fluid's dielectric losses should not become excessive. The LFH fluid should not be allowed to become so deteriorated or contaminated that it adversely affects other materials in the apparatus, nor should deterioration products (sludge) impair its circulation through cooling ducts. If the purpose of using an HMWH is to comply with NEC Article 450-23 requires that less flammable transformer liquids have an ASTM D92 fire point of not less than 300 °C and that the installation complies with all restrictions provided for in the listing of the fluid.

1.4 Background information

1.4.1 Mixtures of LFH fluids with other liquids

LFH fluids are miscible and compatible with other hydrocarbon insulating liquids as well as with halogenated hydrocarbons. Mixtures with conventional transformer oil will lower the flash and fire points of the LFH fluid. If the fire point (ASTM D92) of the contaminated LFH fluid is less than 300 °C, the transformer will not meet the requirements of NEC Article 450-23.

1.4.2 Mixtures of different types of LFH fluids

Although in many cases different types of LFH fluids are miscible (e.g., synthetic hydrocarbons, petroleum-based hydrocarbons), such mixtures should generally be avoided in transformers and fluid processing equipment due to a possible unacceptable decrease in flash and fire points. Consult the manufacturer of each fluid for advice if mixing has occurred or is necessary.

2. References

The following references should be used in conjunction with this guide. When any of the following standards is superseded by an approved revision, the revision shall apply.

ASTM D5222-92, Standard Guide for High Fire-Point Electrical Insulating Oils of Petroleum Origin.[3]

IEC 60156: 1995, Insulating liquids—Determination of the breakdown voltage at power frequency—Test method.[4]

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[3]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

[4]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (http://www.ansi.org/).

IEEE Std 637-1985 (Reaff 1992), IEEE Guide for the Reclamation of Insulating Oil and Criteria for Its Use.[5]

IEEE Std 799-1987 (Reaff 1992), IEEE Guide for Handling and Disposal of Transformer Grade Insulating Liquids Containing PCBs.

IEEE Std 980-1994, IEEE Guide for Containment and Control of Oil Spills in Substations.

IEEE Std C57.104-1991, IEEE Guide for the Interpretation of Gases Generated in Oil-Immersed Transformers.

NFPA 70-1999, National Electrical Code® (NEC®).[6]

Annual Book of ASTM Standards, Section 5, "Petroleum Products, Lubricants, and Fossil Fuels," vol. 5.01.

Annual Book of ASTM Standards, Section 10, "Electrical Insulation and Electronics," vol. 10.03.

3. List of acronyms and abbreviations

DBP	2,6-Ditertiary-Butyl Phenol
DBPC	2,6-Ditertiary-Butyl ParaCresol
HMWH	high molecular weight hydrocarbon
LFH	less flammable hydrocarbon
MSDS	material safety data sheet
SIC	specific inductive capacity
SUS	Saybolt Universal seconds

4. Fluid tests and the significance of each test

Many established ASTM tests of practical significance can be applied to insulating fluids.

The list of tests (see Table 1) and the significance of each test (see 4.1 through 4.21) are offered for classification purposes. It is recommended that these tests be the latest revisions accepted as standards by ASTM.

4.1 Neutralization number (D664, D974)

The neutralization number for service-aged fluids is, in general, a measure of the acidic constituents of the fluid and may be pertinent, if compared to the value for the new product, to detect contamination by substances with which the fluid has been in contact, to reveal a tendency toward chemical change or deterioration, or to indicate chemical changes in additives. It may be used as a general guide for determining when an oil should be replaced or reclaimed, provided suitable rejection limits have been established and confirma-

[5]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[6]The NEC is available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA (http://www.nfpa.org). Copies are also available from the IEEE.

Table 1—Fluid tests

Significance (see subclause listed below)	Test	ASTM method number
4.1	Neutralization number	D664, D974
4.2	Dielectric breakdown voltage	D877, D1816
4.3	Dielectric breakdown voltage (impulse conditions)	D3300
4.4	Interfacial tension	D971
4.5	AC loss characteristics (dissipation factor and relative permittivity)	D924
4.6	Color	D1500
4.7	Viscosity	D88, D445, D2161
4.8	Flash point and fire point (Cleveland open cup method)	D92
4.9	Specific gravity (relative density)	D1298
4.10	Pour point	D97
4.11	Volume resistivity (specific resistance)	D1169
4.12	Gas analysis	D2945, D3284, D3305, D3612, D3613
4.13	Inorganic chlorides and sulfates	D878
4.14	Corrosive sulfur	D1275
4.15	Oxidation stability or sludge formation, or both	D2112, D2440
4.16	Water in insulating fluid (extraction and Karl Fischer methods)	D1315, D1533
4.17	Oxidation inhibitors in electrical insulating fluids	D2668, D4768
4.18	Visual examination field test	D1524
4.19	Refractive index and specific optical dispersion	D1807
4.20	Gassing of insulating oils under electrical stress and ionization	D2300
4.21	Aniline point and mixed aniline point of petroleum products	D611

tion is received from other tests. Method D664 is recommended for dark-colored LFH fluids. Because the end point is determined potentiometrically, the color of the oil does not interfere with Method D664.

4.2 Dielectric breakdown voltage (D877, D1816)

The dielectric breakdown voltage of an insulating fluid is of importance as a measure of its ability to withstand electric stress without failure. It is the voltage at which breakdown occurs between two electrodes under prescribed test conditions. It serves primarily to indicate the presence of contaminating agents (i.e., water, dirt, conducting particles in the liquid), one or more of which may be present when low dielectric breakdown values are found by test. However, a high dielectric breakdown voltage does not indicate the absence of all nonpolar contaminants.

Care must be taken when filling the test cell with LFH fluids to guard against trapping air bubbles, which may result in misleading, low breakdown voltages.

The following two methods are recognized for measuring the power frequency dielectric breakdown voltage of an oil:

— Method D877 is recommended for the routine acceptance of new fluid as received in bulk tankers from a vendor. Method D877 uses flat-faced cylindrical electrodes with a 0.1 inch gap.
— Method D1816 prescribes the use of spherically capped VDE electrodes (as described in Method IEC 60156). It is sensitive to small amounts of contaminants. This method is not recommended for the acceptance testing of new, unreprocessed fluids as received in bulk tankers from a vendor. Method D1816 is the preferred method for use with bulk fluid after processing by the transformer manufacturer. It is also recommended for testing new fluid in new equipment, particularly for high-voltage apparatus. Its significance for evaluating service-aged oils is being determined. While the suitability of Method D1816 has not been determined for oils having viscosities of more than 1.9×10^{-5} m^2/s at 40 °C, several manufacturers and users have reported satisfactory experiences using 2 mm (0.08 in) electrode spacing.

4.3 Dielectric breakdown voltage (impulse conditions) (D3300)

Insulating fluids used in high-voltage apparatus are subjected to transient voltage stresses arising from such causes as nearby lightning strikes and high-voltage switching operations as well as being subjected to steady-state voltage stresses associated with continuous operation of the apparatus at commercial power frequencies. The ability of the insulating fluid to withstand such transient voltage stresses has become increasingly important to determine, as the use of oil-filled apparatus has been extended to operating voltages of 345 kV and higher (extra-high and ultra-high voltage). Breakdown voltage is of primary importance to the designers of such equipment. Its importance to other types of apparatus has yet to be determined.

Transient voltages caused by lightning and switching surge phenomena may be either negative or positive in polarity. Although polarity of the voltage wave has little or no effect on the breakdown strength of an oil in uniform fields, polarity does have a marked effect on the breakdown voltage of an oil in nonuniform electric fields.

The transient voltages already referred to may also vary over a wide range in both the time to reach crest value and the time to decay to half crest or to zero magnitude. The IEEE standard impulse test specifies a 1.2-by-50-µs negative polarity wave. The standard wave shape for switching surge tests on transformers is 100 µs to crest and greater than 1000 µs to zero.

The purchaser of an impulse generator may want to specify the necessary flexibility to make possible switching surge tests. Consideration may be given to other electrode configurations such as VDE electrodes, which are similar to those used in Method D1816, since it may be desirable to obtain the ratio between power frequency and impulse breakdown under similar conditions.

Care must be taken when filling the test cell with LFH fluids to guard against trapping air bubbles, which may result in misleading, low breakdown voltages.

4.4 Interfacial tension (D971)

This method covers the measurement, under equilibrium conditions, of the interfacial tension of insulating fluids against water. The interfacial tension between electrical insulating fluids and water is a measure of the molecular attractive force between their unlike molecules at the interface. It is expressed in dyne/cm (mN/m). This test provides a means of detecting soluble polar contaminants and products of deterioration. Soluble-contamination or fluid-deterioration products generally decrease the interfacial tension value.

Interfacial tension values of new, uncontaminated hydrocarbon fluids of different types may vary because of their differing chemical structures.

NOTE—Interfacial tension test by Method D2285 is not recommended for HMWH fluids, due to the great difference in viscosity between these fluids and water.

4.5 AC loss characteristics (dissipation factor and relative permittivity) (D924)

This method covers the determination of dissipation factor and relative permittivity of new electrical insulating fluids as well as liquids in service or subsequent to service in transformers and other electrical apparatus.

Dissipation factor (power factor) is a measure of the dielectric losses in an electrical insulating fluid when used in an alternating electric field and of the energy dissipated as heat. A low dissipation factor indicates low dielectric losses. Dissipation factor may be useful as a means of quality control and as the indication of changes in quality resulting from contamination, deterioration in service, or handling.

Relative permittivity, often referred to as dielectric constant and occasionally as specific inductive capacity (SIC), is the ratio of the capacitance of a capacitor made with the material to be measured as the dielectric to the capacitance of a capacitor with vacuum dielectric as the dielectric, both having identical electrodes. Low relative permittivity is desired for applications that require low losses. For most materials, relative permittivity increases as temperature increases.

4.6 Color (D1500)

A low color number of a mineral insulating oil is desirable to permit inspection of assembled apparatus in a tank. An increase in color number during service is an indicator of oil deterioration or contamination of the mineral insulating oil. For LFH fluids, which may be initially darker in color, other tests (such as dissipation factor, neutralization number, and interfacial tension) are commonly used to detect fluid deterioration or contamination.

4.7 Viscosity (D88, D445, D2161)

The viscosity of a fluid is its resistance to uniform and continuous flow without turbulence, inertia, or other forces. The viscosity of insulating oil and LFH fluids is usually measured by the time of flow of a given quantity of oil under controlled conditions. Viscosity is not significantly affected by fluid contamination or deterioration but may be useful for identifying certain types of service-aged insulating fluid.

The viscosity at the operating temperatures of electrical insulating oils and hydrocarbon fluids influences their heat transfer properties in convective and pumped flow and, consequently, the temperature rise of energized electrical apparatus containing them.

Method D88 units are in Saybolt Universal seconds (SUS) while Method D445 units are in kinematic centistokes (cSt) or (mm^2/s). Method D2161 converts cSt to SUS units.

4.8 Flash point and fire point (Cleveland open cup method) (D92)

The flash point of a flammable liquid is the lowest temperature at which the vapor pressure is sufficient to form a flammable mixture with air near the surface of the liquid or within a container. The fire point is the lowest temperature at which a liquid in an open container will attain a vapor pressure sufficient to continue to burn when once ignited. Low values of either may be used to provide a qualitative indication of contamination with more flammable materials. Fire point values less than 300 °C may require reclassification or replacement of the LFH fluid, depending upon the particular installation involved. If the purpose of the

HMWH installation is to comply with the NEC, Article 450-23 requires a D92 (Cleveland open cup method) fire point of at least 300 °C.

This method should be used to measure and describe the properties of liquids in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of liquids under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment, which takes into account all of the factors that are pertinent to an assessment of the fire hazard of a particular end use.

4.9 Specific gravity (relative density) (D1298)

The specific gravity (relative density) of an insulating fluid is the ratio of the weights of equal volumes of fluid and water at 15 °C or 60 °F. Specific gravity is not significant in determining the quality of a fluid, but it may be pertinent in determining suitability for use in specific applications. In certain cold climates, ice may form in equipment exposed to subzero (°C) temperatures and may float on a fluid of high (e.g., greater than 0.91) specific gravity.

4.10 Pour point (D97)

The temperature at which insulating fluids will just flow under the prescribed conditions is known as the pour point.

The pour point of a transformer oil or hydrocarbon fluid is important because it indicates the temperature below which oil circulation may be difficult, if not impossible. Even above the pour point temperature, oil circulation may be limited by viscosity.

The pour point has little significance as far as contamination or deterioration is concerned, but it may be useful for type identification and for determining the type of equipment in which it can be used.

4.11 Volume resistivity (D1169)

The volume resistivity of a liquid is a dc measurement of its electrical insulating capability. The resistivity (specific resistance) in ohm-cm of a fluid is the ratio of the direct potential gradient in V/cm paralleling the current flow within the sample to the current density in A/cm^2, at a given instant of time and under prescribed conditions. A low resistivity normally indicates the presence of conductive contaminants, but the test has not been widely applied to service-aged fluids.

4.12 Gas analysis

Thermal and electrical stresses can generate gases within the tank. The gases can appear both as dissolved gas in the liquid and as free gas in the head space. IEEE Std C57.104-1991 is also applicable for nonsynthetic HMWH-based LFH liquids. The key ASTM tests related to gases generated in liquid-insulated transformers are

- — Test methods for gas content of insulating oils (D2945)
- — Standard test method for combustible gases in the gas space of electrical apparatus in the field (D3284)
- — Method for sampling gas from a transformer (D3305)
- — Test methods for analysis of gases dissolved in electrical insulating oil by gas chromatography (D3612)
- — Test methods for sampling electrical insulation oils for gas analysis and determination of water content (D3613)

4.13 Inorganic chlorides and sulfates (D878)

This test indicates the presence of inorganic chlorides and sulfates by precipitation of insoluble salts using the usual analytical procedures. The presence of inorganic chlorides or sulfates is an indication of corrosiveness of the fluid and of the presence of contaminants.

4.14 Corrosive sulfur (D1275)

This test is designed to detect the presence of free sulfur and combined corrosive sulfur by subjecting copper to contact with fluid under prescribed conditions. This test indicates the possibility of corrosion resulting from the presence of either free sulfur or unstable sulfur compounds.

4.15 Oxidation stability or sludge formation, or both (D2112, D2440)

These methods are for the evaluation of the oxidation stability of new hydrocarbon insulating oils containing oxidation inhibiters. These tests are considered of value in checking the oxidation stability of new hydrocarbon insulating oils containing 2,6-Ditertiary-Butyl ParaCresol (DBPC) or 2,6-Ditertiary-Butyl Phenol (DBP), or both, in order to control the continuity of this property from shipment to shipment. While the applicability of this procedure for use with inhibited insulating fluids with a viscosity of more than 1.2×10^{-5} m^2/s at 40 °C (120 cSt) (approximately 65 SUS at 100 °F) has not been fully established, several laboratories have reported satisfactory experiences using this method with several LFH fluids.

4.16 Water in insulating fluid (extraction and Karl Fischer methods) (D1315, D1533)

Water may be present in insulating fluids in several ways. The presence of free water may be disclosed by visual examination; it may be in the form of separated droplets or as a cloud dispersed throughout the fluid. This type of water invariably results in decreased dielectric strength, which may be restored by filtration or other suitable means. Water in solution, which does not decrease the dielectric strength of the fluid, cannot be detected visually and is normally determined by either physical or chemical means. Both methods cited are suitable for the determination of water in insulating fluids and, depending upon the conditions of sample handling and the method of analysis, can be used to estimate the total water content of fluids. The unit measure of the water is in parts per million. These tests are significant in that they will show the presence of water even if it may not be evident from electrical tests.

4.17 Oxidation inhibitors in electrical insulating fluids (D2668, D4768)

Both DBPC and DBP are oxidation inhibitors commonly used in insulating fluids to provide added protection against oxidation in insulation systems during service life. Oxidation inhibitor effectiveness is a function of base fluid type, freedom from contamination, and concentration. Consequently, methods are provided to assay the concentration of these inhibitors in insulating fluids, and although not originally intended for use with LFH fluids, may be of use in determining inhibitor content in LFH fluids.

Method D2668 uses infrared absorption, and Method D4768 uses gas chromatography.

4.18 Visual examination field test (D1524)

This test gauges the color and turbidity (cloudiness) of a fluid, which may indicate the presence of free water or sediment (i.e., metal particles, insoluble sludge, carbon, fibers, dirt). If insoluble contaminants are present, valuable information may be obtained by filtering the fluid and identifying the residue.

4.19 Refractive index and specific optical dispersion (D1807)

The refractive index of an insulating fluid varies with its composition and with the nature and amount of contaminants held in solution. Refractive index may also be useful for identifying chemically different types of hydrocarbon and LFH fluids. For service-aged fluids, the refractive index may be pertinent, if compared to the value for the new product, to detect and estimate any change in composition or degree of contamination.

Specific optical dispersion serves as a quick index for the amount of unsaturated compounds present in a fluid.

These tests have not been widely applied to service-aged fluids.

4.20 Gassing of insulating oils under electrical stress and ionization (D2300)

For certain applications, when insulating fluid is stressed at high-voltage gradients, it may be desirable to be able to determine the rate of gas evolution or gas absorption under specified test conditions. At the present time, correlation of such test results with equipment performance is limited.

4.21 Aniline point and mixed aniline point of petroleum products (D611)

Aniline point is the minimum equilibrium solution temperature for equal volumes of aniline and test sample. It is most commonly used to estimate the aromatic content of the sample. The higher the number, the lower the aromatic content. Paraffinic-hydrocarbon-based LFHs should have significantly higher aniline values compared to naphthenic-based transformer oils. Aniline point is also an indicator of the relative solvency of the test sample for materials in contact with it. Aniline point may indicate the relative impulse and gassing characteristics of the sample.

5. Handling and evaluation of LFH fluids for use in filling transformers at the installation site

NOTE—Manufacturer’s instructions for field preparation and fluid filling vary because of differences in the design of units and individual preference. Some sites demand more rigorous quality control. The user and the manufacturer should agree on minimum standards. All handling equipment (e.g., hoses, pipes, tanks) should be kept clean and dedicated to LFH service.

5.1 Shipping containers

LFH fluids are shipped in drums, railroad tank cars, and tank trailers, all of which should be clean and dry.

5.2 Check tests on receipt

The inspection of LFH fluids should follow similar procedures as those now being used for transformer oil. Fluid received in tank trailers should be tested prior to unloading.

Accurate sampling, whether of the complete contents or only part thereof, is extremely important from the standpoint of evaluation of the quality of the product sampled. Obviously, careless sampling procedures or contamination in the sampling equipment will result in a sample that is not truly representative. This misrepresentation generally leads to erroneous conclusions concerning quality. The appropriate procedures and precautions outlined in the latest revision of ASTM Method D923, Sampling electrical insulating liquids, should be followed.

Upon receipt, LFH fluids meeting or exceeding the values presented in Table 2 are considered to be acceptable. Values shown in Table 2 are generic to LFH fluids as a class. Specific typical values for each different brand of fluid should be obtained from the fluid manufacturer.

Table 2—Acceptable values for receipt of bulk shipments of LFH fluids[a]

ASTM method	Test	Results	
		Minimum	Maximum
D1298	Specific gravity (25 °C)	—	0.86–0.90
D92	Flash point (°C)	275	—
D92	Fire point (°C)	300	—
D445	Kinematic viscosity, mm^2/s, (cSt) 0 °C 40 °C 100 °C	 1.0×10^3 1.0×10^2 1.0×10^1	 2.5×10^3 1.3×10^2 1.4×10^1
D97	Pour point (°C)	—	–21
D1500	Color, ASTM	—	2.5
D974	Neutralization number, mg KOH/g	—	0.03
D1533	Water content, ppm	—	35
D877	Dielectric breakdown, kV	25	—
D924	Dissipation factor,% 25 °C 100 °C	—	 0.05 0.30
D971	Interfacial tension, mN/m (dyne/cm), 25 °C	40	—

[a]The test limits shown in this table apply to LFH fluids as a class. Specific values for each brand of fluid should be obtained from each fluid manufacturer.

5.3 Handling of the fluid by the user and placing the fluid in storage

Direct transfer from the delivery container to the transformer is not always possible. It may be necessary to install the LFH fluid in storage tanks.

Where the manufacturer’s instructions differ from recommendations made in this guide, the manufacturer’s instructions are to be given preference. The location and style of storage tank will depend on the user’s physical plant arrangement.

An indoor tank location is ideal, if space is available. The indoor location reduces the need for heating to maintain proper pumping and filtering temperatures. Outdoor tanks should be well insulated to minimize the effect of winter temperatures.

Normally, LFH fluids can be pumped directly from either the inside or underground storage tanks. However, if suction line lengths or suction lifts are excessive, relative to the ambient temperature, heating of the fluid may be required. If heating of the fluid is required, care should be taken in heater selection so that localized surface temperatures do not exceed 288 °C (550 °F) to prevent scorching.

A suction heater placed directly in the tank can be used if heating the fluid to a satisfactory pumping temperature is required. This approach is usually the most economical because heat need only be applied when fluid is to be pumped from the tank.

A circulation pump and electric heater can be piped to the storage tank to maintain warm temperatures.

5.3.1 Tanks

Standard storage tanks, such as those used for transformer oil, are satisfactory. All tanks should conform to local codes and standards. New tanks should be specified with openings that are properly threaded and should have at least one manhole. The inside of the tanks should be sandblasted and primed with a coating that is compatible with the LFH fluid, such as an alkyd primer. Generally, any coating that is compatible with conventional transformer oil will prove satisfactory for LFH fluid use.

Existing storage tanks that have been used for transformer oil can be used for LFH fluids if the following conditions are met:

— Transfer pumps and lines are of adequate capacity to pump the more viscous fluid. If the tank and transfer system are situated so that the fluid may have to be moved while it is cold, use of electric- or steam-line bracing and tank-heating apparatus may be necessary.
— The tank is thoroughly cleaned and inspected for rusting conditions or leakage.
— The tank should be thoroughly drained and flushed with hot LFH fluid before being filled to avoid lowering the fire point of the LFH fluid by contamination.

5.3.2 Venting

It is recommended that all storage tanks be blanketed with dry nitrogen or equipped with a desiccant-type vent dryer to minimize the introduction of moisture into the fluid. Proper routine maintenance of the desiccant is essential.

Equipping a tank with a proper pressure/vacuum vent valve and dryer lowers the dew point of the air in the tank to help prevent condensation of moisture.

Each vent dryer should have an indicator to show when desiccant should be changed. Changes should be planned in advance of the anticipated indicator change.

Freeze drying (dehumidification) of the air in the storage tank can also be used.

A tank vent filter between the desiccant canister and the tank is also recommended. Filtering incoming air to the tank may prevent introduction of airborne particulate material into the fluid during storage.

5.3.3 Pumps

— *Capacity.* Since the viscosity of LFH fluids is generally higher than ordinary transformer oil, care must be used in selecting a pump with the horsepower and capacity required. First, determine the maximum flow rate required and then select a pump and motor that will handle this flow rate at the lowest temperature (highest fluid viscosity) that will be encountered.
— *Type*. The most commonly recommended pump for LFH fluids is the positive displacement gear pump. A standard iron pump with either mechanical seal or stuffing box is also satisfactory.

So that pump suppliers can specify the correct pump size, they should be made aware of the fluid viscosity and the required pumping rate, suction lift, and discharge head.

For capacities up to 20 gpm (4.8 L/s), direct-driven pumps have proven to be satisfactory. For higher pumping rates, a reduction-gear or belt-driven pump may be required.

Other pumps that have been used successfully are the air-operated diaphragm pump, progressive cavity pump, and flexible impeller pump.

5.4 Handling and testing of LFH fluids for installation into apparatus

The preferred method of filling transformers is under full-vacuum conditions. Additional vacuum processing of the LFH fluid is recommended if excessive bubbling occurs.

Where instructions given by the transformer manufacturer differ from recommendations made in this guide, the manufacturer’s instructions are to be given preference.

NOTE 1—Do not exceed the transformer tank vacuum limits (see nameplate or contact the transformer manufacturer for information) or tank damage may result.

Commercial degasification and dehydration units are available that can process fluids to acceptable levels of dissolved moisture and dissolved air.

The degasification of LFH fluids should be carried out at temperatures somewhat higher than those required for ordinary transformer oils. The processing temperature should be at least 70 °C at a vacuum of 66.7 Pa to 220 Pa. These conditions will ensure thorough degasification and dehydration of the LFH fluid prior to introduction into the transformer.

After the LFH fluid is processed through the degasifier and particulate filter, it should be introduced directly into the transformer under vacuum. If in doubt as to the filling procedure to be followed, seek guidance from the transformer manufacturer. If guidance from the transformer manufacturer cannot be obtained, a storage tank that can maintain a vacuum equal to or greater than the vacuum maintained in the transformer will be required. If the recommended vacuum cannot be achieved, the LFH fluid may exhibit excessive bubbling during the filling operation, depending on the amount of air and moisture that may have dissolved into the LFH fluid.

In instances where the equipment must be filled on site, without the use of vacuum impregnation, consult the fluid manufacturer for instructions concerning fill rate and characteristics of the fluid after filling.

NOTE 2—Take care to avoid LFH contamination with conventional transformer oil in order to prevent lowering the fire point. NEC Article 450-23 requires a minimum D92 fire point of 300 °C for less flammable transformer liquids. Dedicated equipment is recommended to avoid such contamination.

6. Evaluation of LFH fluids received in new equipment and after filling apparatus on site

In sampling fluid that is contained in apparatus, care must be used in order to obtain a representative sample. Method D923 should be followed. LFH fluids exhibiting the characteristics presented in Table 3 are considered acceptable.

Table 3—Acceptable values for LFH fluids received in new equipment[a]

ASTM method	Test	Results		
		Minimum		Maximum
D1816	Dielectric breakdown voltage for 0.08 in gap, kV	40 50 60	34.5 kV class and below Above 34.5 kV class Desirable	—
D1816	Dielectric breakdown voltage for 0.04 in gap, kV	20 25 30	34.5 kV class and below Above 34.5 kV class Desirable	—
D974	Neutralization number, mg KOH/g	—		0.03
D877	Dielectric breakdown voltage, kV	30		—
D924	AC loss characteristic (dissipation factor),% 25 °C 100 °C	—		 0.1 1
D1533B	Water content, ppm	—		25
D1524	Condition—visual	Clear		
D92	Flash point (°C)	275		—
D92	Fire point (°C)	300[b]		—
D971	Interfacial tension, mN/m, 25 °C	38		—
D445	Kinematic viscosity, mm^2/s, (cSt), 40 °C	1.0×10^2 (100)		1.3×10^2 (130)
D1500	Color	—		L2.5

[a]The test limits shown in this table apply to LFH fluids as a class. Specific typical values for each brand of fluid should be obtained from each fluid manufacturer.
[b]If the purpose of the HMWH installation is to comply with the NEC, this value is the minimum for compliance with NEC Article 450-23.

After the filling is completed and the standing time is also completed, tests on the LFH fluid should be made before energization of the transformer (see Table 3).

Most manufacturers have found it advisable to allow LFH-fluid-filled transformers to stand at least several hours after filling and vacuum breaking, or until the transformer has cooled to room temperature before energizing or high-voltage testing. Transformers with heavy thicknesses of pressboard insulation will require standing times that are adequate to allow full saturation. Impregnation rate is a function of fluid temperature and the thickness of the cellulose material to be saturated. Refer to the transformer and fluid manufacturers for guidance concerning saturation rates.

Fluid-circulating pumps, if any, should be operated for at least several hours of this time. Most transformer manufacturers have specific written procedures for this standing time and pump operation, and they should be consulted for their recommendations.

7. Maintenance of LFH fluids

For the purposes of this guide, reconditioning is defined as “the removal of moisture and solid materials by mechanical means,” while reclaiming is defined as “the removal of acidic and colloidal contaminants and oxidized matter by chemical and adsorbent means.”

7.1 Field screening

Field screening of LFH fluids should follow the procedures now being used for transformer oil. Experience in this matter indicates that visual condition and dielectric breakdown voltage are the most applicable screening methods. A sample should be drawn in a clean, clear glass or high-density polyethylene jar. Aluminum or tin-plated steel cans may also be used as containers for the samples. The fluid should then be checked for clarity, color, odor, and viscosity (relative to a known clean sample). Dielectric breakdown voltage should then be measured. Portable dielectric test sets have been available for some time and have proven quite satisfactory in determining whether additional laboratory screening is necessary.

7.2 Laboratory screening

Fluids that have unsatisfactory appearance and dielectric values should be further evaluated. The following tests are adequate for classifying service-aged LFH fluids.

— Visual condition (D1524)
— Color (D1500)
— Neutralization number (D664, D974)
— Dielectric breakdown voltage (D1816)
— Interfacial tension (D971)
— Water content (D1533)
— AC loss characteristic (dissipation factor) (D924)
— Fire point (D92)

The following tests are usually not required for classifying service-aged fluids. They may be useful, however, in more completely characterizing the condition of such fluids.

— Inhibitor content (D2668, D4768)
— Viscosity (D88, D445, D2161)[7]
— Specific gravity (D1298)
— Pour point (D97)
— Corrosive sulfur (D1275)

7.3 Test limits for service-aged LFH fluids

As a guide to be used in the absence of the manufacturer’s recommendations, acceptable limits for service-aged LFH fluids are shown in Table 4.

[7]Method D445 is the preferred for measuring viscosity because it is far more accurate than Method D88.

Table 4—Acceptable values for continued use of service-aged LFH fluids[a]

ASTM method	Test	Values for continued service	
		Minimum	Maximum
D1816	Dielectric breakdown voltage for 0.04 in gap, kV	23	—
D1816	Dielectric breakdown voltage for 0.08 in gap, kV	34	—
D877	Dielectric breakdown voltage, kV	24	—
D664	Neutralization number, mg KOH/g	—	0.20
D924	AC loss characteristic (dissipation factor 60 Hz),%, 25 °C	—	1.0
D1533B	Water content, ppm	—	35
D92	Fire point, °C	300[b]	—
D971	Interfacial tension, mN/m, 25 °C	24	—

[a]The values in this table are considered typical for acceptable service-aged LFH fluids as a general class. If actual test analyses approach the values shown, consult the fluid manufacturer for specific recommendations.
[b]If the purpose of the HMWH installation is to comply with the NEC, this value is the minimum for compliance with NEC Article 450-23.

7.4 Reconditioning

The mechanical means that are used for removing water and solids from fluids include several types of filters, centrifuges, and vacuum dehydrators. In general, moisture removal filters and vacuum dehydrators should be placed before the final particulate removal filters.

7.4.1 Moisture removal

If, during the transport or storage of the fluid, moisture is introduced into the fluid above a limit that would not permit the fluid to be introduced into a transformer, additional treatment will be required.

7.4.1.1 Free moisture removal

If the moisture is in the form of free water, filter elements utilizing blotter paper have been used effectively. Filter cartridges packed with a desiccant are recommended to ensure dryness. Otherwise, the filter elements should be oven dried before use. Take care not to exceed the manufacturer's temperature rating of the elements. Do not exceed 140 °C for paper drying media.

Coalescing filters may be of use where larger quantities of free water are present.

Molecular sieve filters are also satisfactory if the quantity of moisture to be removed is not excessive. Activated grade 3A or 4A molecular sieves are recommended for moisture removal from LFH fluids and are effective over a broad temperature range, provided adequate care is taken in filter selection to ensure sufficient residence time in the filter and a particulate filter is used downstream of the molecular sieve filter.

Activated calcium sulfate can also be used to dry LFH fluids. Again, system design should ensure adequate residence time in the moisture removal filter, and a particulate filter should be used downstream of the activated calcium sulfate filter.

Most types of filters now being used on transformer oil can be used for LFH fluids.

The cartridge-type filter is well suited for this service. It is offered in various nominal pore size ranges, and sizes for either low or high flow rates are available.

Filters of the adsorption type, such as activated Fuller's earth, can be used; however, certain pour point depressant and antioxidant additives may be removed from the fluid by these filters. The manufacturer of the fluid should be consulted to determine whether the possibility of additive removal is a concern.

Just as when selecting pumps, care should be taken in selecting a filter for LFH fluids. Since LFH fluid viscosities are higher than those for transformer oil, larger filters will be required to achieve the same flow rate.

If existing filters are to be used, the flow rates might have to be decreased as much as 50% unless steps are taken to decrease the fluid viscosity by heating.

7.4.1.2 Dissolved moisture removal

If the dissolved moisture content must be lowered, a high vacuum dehydration system may be required. The vacuum dehydrator is an efficient means of reducing the gas and water content of an insulating fluid to a very low value. Two types of vacuum dehydrators are in general use today. The operating principle of both is the same, i.e., the fluid is exposed to a high vacuum and heat for a short interval of time. In one method, the exposure of the fluid is accomplished by spraying the fluid through a nozzle into a vacuum chamber. In the other type of vacuum dehydrator, the fluid is allowed to flow over a series of baffles inside a vacuum chamber, thus forming thin films so that a large surface is exposed to the vacuum. If the fluid contains solid matter, it is advisable to filter it before processing it in the vacuum dehydrator because solid contaminants may plug the nozzle of one type of dehydrator or pass through either type without being removed from the fluid.

In addition to removing water, vacuum dehydrators will degas the fluid and remove any volatile acids. Most acids, however, will be relatively unaffected, and it is doubtful whether the overall acidity of the fluid will be much improved by the vacuum dehydration method. In either type of dehydrator, some means of automatically recirculating a very wet fluid should be provided as a safety device to prevent an excessive water content in the outgoing fluid.

7.5 Reclaiming

The removal of deterioration products is usually accomplished by the use of reclaiming processes involving Fuller's earth alone or in combination with certain chemicals, such as alkali salts. A number of these processes are outlined for use with transformer oil in IEEE Std 637-1985.

The manufacturer of the fluid should be consulted for recommendations regarding reclaiming, as the recommended treatments may vary from those outlined in IEEE Std 637-1985 and some additives provided with new fluid may be removed by the reclamation process and may need to be added to the reclaimed fluid.

7.6 Mixtures of different types of LFH fluids

Although in most cases different types of LFH fluids are miscible, such mixtures should generally be avoided in transformers and fluid processing equipment due to possible chemical or dielectric incompatibilities. Consult the manufacturers of the fluids or the transformer for advice if mixing is permissible or has occurred.

In most cases, mixtures with conventional mineral oil should be avoided to prevent a reduction in the flash and fire points. In all cases, even trace contamination by 50 cSt silicone fluid is to be avoided due to potential problems of foaming and lowering dielectric strength.

8. Safety and environmental care procedures

Users should obtain a material safety data sheet (MSDS) for each LFH fluid in use. Where manufacturer's instructions differ from recommendations made in this guide, the manufacturer's instructions are to be followed. Although no special risk is involved in the handling and use of the LFH fluids addressed in this guide, attention is drawn to the general need for washing skin and clothing that may come in contact with the fluid. Personnel should avoid eye/fluid contact. Although not listed as a hazardous waste by any federal agency, disposal of LFH fluids requires certain precautions to avoid risk of environmental pollution; and local legal requirements may apply. The same precautions and regulations applicable to handling of conventional mineral oil are recommended for LFH fluid. (See IEEE Std 799-1987 and IEEE Std 980-1994.)

8.1 Leaks

During a regular maintenance schedule, routine checks should be made for leaks. Areas to check and repair should include valves, bushings, gauges, tap changers, welds, sample ports, manhole covers, pipe fittings, and pressure relief valves. If the leak does not involve a replaceable seal, welding or epoxy sealing kits may be used to seal it.

Proper care must be taken to protect the integrity of the LFH fluid and equipment insulation if leak repair requires lowering the liquid level. Clean and dry temporary fluid storage containers must be used. Testing of the fluid before returning it to the equipment is necessary. The recommendations on sampling, testing, and filling of transformers presented in this guide should be followed.

8.2 Minor spills

Minor spills, such as those occurring in the manufacture or repair of transformers and in testing LFH fluid, can be cleaned using absorbent rags. Using suitable solvent facilitates cleanup. Most common solvents are suitable for use with LFH fluids. However, flammability and toxicity should be prime considerations when choosing a solvent.

8.3 Spills on soil

Soil acts as an absorbent; and, if the presence of LFH fluid is objectionable, the soil can be removed to a landfill area and replaced with fresh soil.

LFH fluids in spill situations behave much the same as motor oil or other hydrocarbons of comparable viscosity. The same cleanup procedures are applicable.

8.4 Spills on water

Because hydrocarbon fluids float on water, a spill can be contained by floating booms or dikes. If containment equipment is unavailable or impractical, the LFH fluid can be concentrated by applying a surface-active chemical designed for this purpose around the perimeter of the spill. If a spill of an HMWH fluid occurs on a navigable waterway, it should be reported to the proper authorities.

Once the LFH fluid has been concentrated, it can be removed from the water surface by systems normally used for petroleum spills. These systems include pumps, skimmers, physical absorbents, and oleophilic hydrophobic fibers that are fabricated into floating ropes. These ropes are moved through the oil-laden water to a machine with wringer rollers and a holding tank and then moved back into the water. This technique has been found to be effective for crude oil spills. When collected, the fluid may be reclaimed or incinerated in a suitable burner.

Annex A

(informative)

Bibliography

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